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Evaluation of Palatability of Cooked Rice

Ken'ichi Ohtsubo and Sumiko Nakamura

Additional information is available at the end of the chapter

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Abstract

Quality evaluations of rice in Japan are performed by sensory testing and physicochemical measurements. The former is a basic method that requires large amounts of samples and several panelists. The latter is an indirect method that estimates the eating quality based on the chemical composition, cooking quality, gelatinization properties, and physical properties of cooked rice. Satake Co Ltd. developed a taste analyzer in the 1980s that is equipped with a palatability estimation formula that was based on the combination of near-infrared spectroscopy (NIR) and physicochemical measurements related with sensory test. A novel method to evaluate the quality of the cooked rice is necessary to breed high-quality rice cultivars and to select the suitable rice for each consumer and each purpose. We try to develop the novel method to evaluate the rice quality using various kinds of apparatus, such as Tensipresser, RVA, NIR, and spectrophotometer. Simple, rapid, and accurate method to evaluate the quality of rice grains is very valuable. We evaluated 16 Japanese and Chinese rice cultivars in terms of their physicochemical properties. Based on these quality evaluations, we concluded that Chinese rice cultivars are characterized by a high protein and that the grain texture after cooking has higher hardness and lower stickiness than Japanese ones reflecting the difference in consumers' preference. The relationship between the palatability of rice and agronomical condition to preserve the bio-diversity for Crested Ibis was investigated. Furthermore, the quality of rice grown in Sado Island, Japan, was assayed using rice grains grown in mountainous areas and in the field areas as samples.

Keywords: palatability, physicochemical measurements, cooked rice

1. Introduction

Rice, wheat, and maize are the most important crops in the world. Rice consumers need sufficient quantities and high-quality rice grains.

The rice quality depends on various aspects such as consumer safety, nutrition, appearance, price level, and palatability. Because rice is eaten every day, it is indispensable that it should

be safe to eat and highly nutritious. Furthermore, because rice provides income for farmers and is prepared, milled, and sold by wholesalers and retailers, the rice yield and price are extremely important to the farmers. Consumers have been asking for more palatable rice because they have recently become more affluent. According to the Food Agency, 45.1% consumers purchase rice grains based on their palatability, 16.3% select it on the basis of its brand name, and 4.8% choose it on the basis of the location of rice production, implying that more than 66% Japanese consumers prefer palatable rice grains to cheaper, nonpalatable rice.

Quality evaluations of rice in Japan are performed by sensory testing and physicochemical measurements. The former is a basic method that requires large amounts of samples and several panelists. The latter is an indirect method that estimates the eating quality based on the chemical compositions, cooking quality, gelatinization properties, and physical properties of cooked rice.

A rapid, simple, and more accurate method is required to evaluate rice. Therefore, if a novel method that used near-infrared spectroscopy could be developed, producers and consumers would have a rapid and nondestructive testing method which assessed the quality of the rice grains.

2. Sensory test

Sensory testing is the fundamental method that evaluates the eating quality of rice grains. The members of a trained panel taste cooked rice samples and give scores on the basis of appearance, flavor, taste, hardness, stickiness, and overall sensory evaluation. The test results can be expressed as numerical values and treated statistically; there are disadvantages to using this test. The results differ depending on the preference of panel members, and the results cannot be directly compared if the time or country differs.

3. Physicochemical evaluations

Physicochemical evaluation [1] is only indirect evaluation of rice palatability, and its results are common all over the world if we use the same method and apparatus. Physicochemical measurements include component analysis, such as protein, amylose, and fibers, pasting properties of starch, texture measurements of the cooked rice grains, etc. For the sake of estimating the total palatability, statistical treatment is adopted using the results of each measurement as the variables. Multiple regression analysis, principal component analysis, and PLS analysis are very useful to clarify the characteristics of the rice samples. Recently, spectrophotometric analyses, such as NIR or visible-light spectrometer, are utilized to estimate the chemical components and to develop the estimation formulae for palatability. "Taste Analyzer" is an example of the NIR system as a nondestructive estimation apparatus for palatability of rice grains. Examples of sensory test and physicochemical evaluation of rice palatability are shown in **Table 1**.

3.1. Amylose content

Amylose content is the most important factor that determines rice quality because starch shares approximately 85% (w/w, dry basis) of the milled rice grains. Because Japanese con-

Sensory test	Physicochemical test
Appearance	Gloss meter, “Mido” meter
Aroma	GC, GCMS, Electric nose
Taste	HPLC, Enzyme kit, Taste sensor, Taste analyzer
Texture	Texturometer, Texture analyzer, Tensipresser
Overall evaluation	Multivariate analysis

Table 1. Evaluation of rice palatability.

sumers prefer soft and sticky cooked rice, low amylose rice is the dominant rice sold in the Japanese rice market. Amylose content is generally measured by the colorimetric method of Juliano [2].

3.2. Protein content

Protein content is another extremely important factor that determines rice quality. Cooked rice with high protein content tends to be hard and nonsticky. Protein content is measured by the Kieldahl or the combustion method.

3.3. Moisture content

Moisture content affects the eating quality of cooked rice. Low-moisture rice grains absorb water faster than high-moisture grains. In cooked rice, the final moisture content from the low-moisture rice grains is higher than that from the high-moisture rice grains. Moisture content is generally measured by the oven dry method.

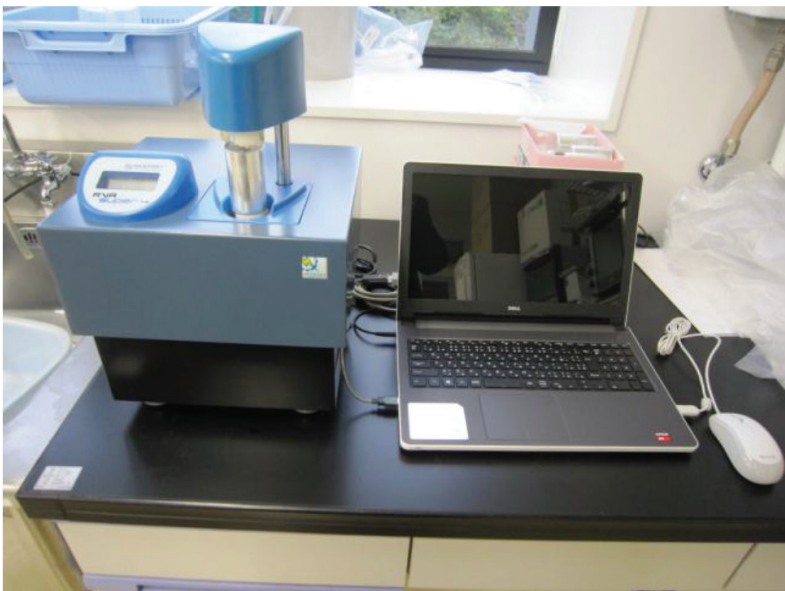


Figure 1. Rapid visco analyzer.

3.4. Gelatinization properties

The maximum viscosity, final viscosity, and “break-down” viscosity (maximum viscosity–minimum viscosity) are measured in an Amylograph. These viscosity measurements were considered good indices for the eating quality of rice. The Rapid-Visco-Analyzer (RVA) was developed in Australia and was recently introduced in Japan (**Figure 1**) [3]. Time (13–19 min) and samples (3.5 g) can be saved using an RVA.

3.5. Fat acidity

Fat acidity is a good index to measure the quality deterioration of rice grains during storage. In Japan, newly harvested rice is preferred to aged rice because consumers like soft and sticky cooked rice. Ohtsubo proposed a new colorimetric method to accurately measure fat acidity [4].

3.6. Cooking quality test

A cooking quality test was developed by the researchers of USDA in the 1950s [5]. An expanded volume and water uptake ratios are measured after cooking rice samples in excess amounts of water. Dissolved amylose is measured by color generation by combining iodine and amylose.

3.7. Physical properties of cooked rice grains

Physical properties of cooked rice grains, such as hardness and stickiness, are measured by a Texturometer, Tensipresser, Texture analyzer, or Rheograph-micro. Low-compression and high-compression test using a Tensipresser [6] is shown in **Figure 2**.

3.8. Palatability estimation formula

Chikubu et al. developed a new equation to estimate the palatability of rice grains using a multiple regression analysis based on physicochemical measurements, such as an amylograph viscosity profile, protein assay, and iodine blue value measurements [7]. The formula showed a high correlation between the results of a sensory test ($R = 0.84$) of the rice samples harvested next year.

3.9. Application of near-infrared spectroscopy to evaluate rice quality

Near-infrared spectroscopy is a rapid, nondestructive, and extremely promising technique to evaluate qualities of the rice grains. In Japan, NIR spectroscopy was initially used to determine the protein and moisture content of the rice flours. Satake Co. Ltd subsequently combined NIR and palatability estimation formula and developed a new system called “Taste Analyzer.”

3.9.1. Protein content

Iwamoto et al. reported that NIR was equally sensitive to both rice and wheat proteins. A standard error of estimation (SEP) was decreased for calibrations using a derivative absorbance.

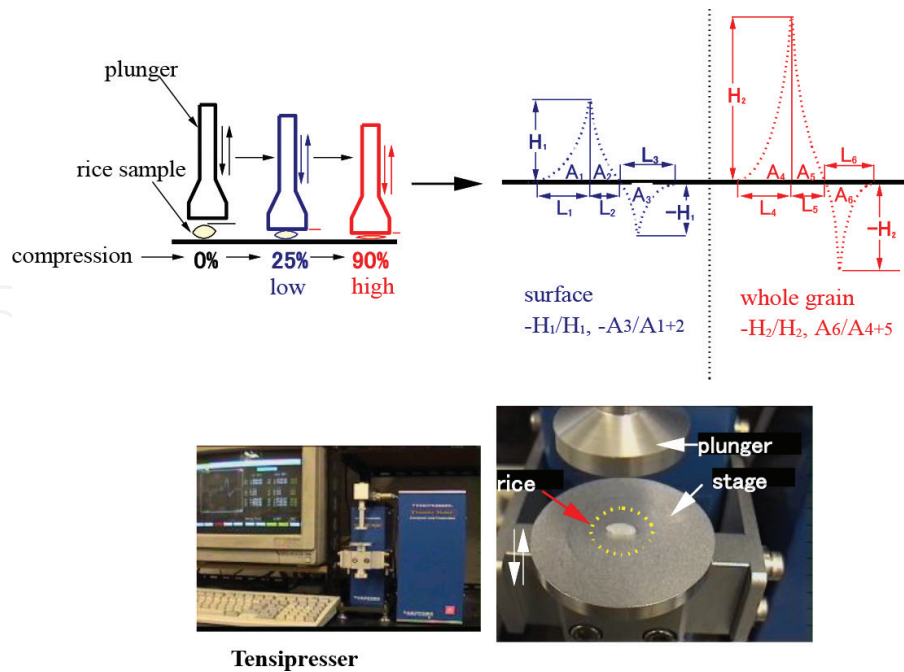


Figure 2. Tensipresser used for texture measurement of cooked rice grains.

However, the derivative procedure may possibly make an increment bias in cases that predict “unknown” samples [8]. Inatsu utilized NIR spectroscopy to select palatable rice cultivars by measuring the protein content of rice because low protein rice is preferred in Japan because of their palatability [9].

3.9.2. Estimation of rice amylose contents by NIR [10]

Japanese rice breeders have tried to develop palatable rice cultivars by selecting low amylose rice; however, the amylose content among Japanese rice grains are not significantly different (15–20%). NIR spectroscopy can easily compare protein and moisture; however, it does not easily differentiate amylose from amylopectin. Villareal and Delwiche had already developed excellent calibrations to detect amylose in various rice samples through NIR spectroscopy [11, 12]. Japanese consumers request high-performance calibration for the measurement of narrow range amylose of Japanese rice cultivars. Apparent amylose content (AAC) analysis is a rapid and simple technique that uses NIT spectroscopy. It was developed based on the near-infrared transmission spectra and the reference value of AAC determined by the iodine colorimetric method. The wide AAC range (0–35.3%) PLS model was inadequate for the accurate prediction of the extremely narrow range of the AAC (13.2–20.7%) of Japanese milled rice samples. The statistics performed on the 11-factor PLS model for the extremely narrow range of AAC analyses was 0.78, 0.74, and 2.01 in SECv, r^2 , and RPD, respectively. The performance of this model was 1.25 and 0.49 for SEP and r^2 , respectively, on the validation set. The previous models developed a wide range of AAC samples, which were difficult to apply to the narrow range of AAC rice. The present AAC analysis technique is based on NIT spectroscopy, which can discriminate between the extremely narrow differences in AAC of Japanese milled rice in the same subfamily.

3.9.3. Eating quality evaluation system by NIR

Satake Co. Ltd. developed a taste analyzer in the 1980s that combined the palatability estimation formula that was based on the physicochemical measurements and NIR. The taste analyzer principle is based on the multiple regression analysis that uses NIR data (protein, moisture, amylose, and fat acidity) against the sensory test results. A previous study by the Japanese Association of Milling Companies evaluated three different types of palatability evaluation system using NIR. The results showed that the taste scores correlated significantly with the results of the sensory test ($r = 0.54\text{--}0.63$), but the scores were affected by the moisture contents and milling yield [13].

There were eight Japanese companies that developed the characteristic systems to evaluate the palatability of rice grains based on the spectroscopic technique. More than 1000 agricultural cooperatives, wholesalers, and retailers introduced these NIR systems to evaluate the quality of their rice grains (**Figure 3**). In 1996, the Japanese Food Agency conducted a survey regarding the palatability evaluation system, and the results showed that 67% users were satisfied with the performance of the system. The protein and moisture data was extremely reliable, but some users requested an improvement in the taste score and amylose accuracy.



Figure 3. Taste analyzer based upon NIR technology.

4. Proposal as novel physicochemical measurement, iodine colorimetric analysis, for rice palatability evaluation [14]

4.1. Introduction

As described in Section 3, physicochemical test is very important because it is time-saving and labor-saving objective test for rice palatability. Main component of rice grains is starch, therefore, amylose content affects eating quality [15]. Low-amylose rice generally becomes soft and sticky after cooking, whereas high-amylose rice becomes hard with fluffy separated grains [16].

The most widely used method for amylose determination is a colorimetric assay where iodine binds with amylose to produce a blue-purple color, which is measured spectrophotometrically at a single wavelength (620 nm) [2].

We here characterized the starch of various rice cultivars; evaluated the relationship between their iodine absorption curve and apparent amylose contents, amylopectin fractions, and resistant starch. We improved the iodine colorimetric method, and developed the novel estimation formulae against the amylose contents, resistant starch, or a certain fractions of definite chain-length amylopectin. This novel method would lead to an easy and low-cost spectroscopic method for analyses of starch characteristics.

4.2. Contents

We used Japonica rice, Indica rice, Indica-Japonica hybrid rice, *ae* mutant rice, and waxy rice produced in Japan and China.

We polished brown rice to a milling yield of 90–91%, using an experimental friction-type rice milling machine (Yamamotoseisakusyo, Co. Ltd., Tendoh, Japan). White rice flour was produced with a cyclone mill (SFC-S1; Udy, Fort Collins, CO, USA). Starch granules were prepared from polished rice flour using the cold alkali method.

The iodine absorption spectrum of the rice starch was measured using a Shimadzu UV-1800 spectrophotometer. The AAC of rice starch was measured by the iodine colorimetric method of Juliano [2]. The iodine absorption spectrum was scanned from 200 to 900 nm. The absorbance was measured at 620 nm, at λ_{\max} (wavelength at the peak between 400 and 900 nm), and absorbance at λ_{\max} ($A\lambda_{\max}$) (Figure 4).

The area of F1 (from B to 400 nm), area of F2 (from 400 nm to λ_{\max}), and area of F3 (from λ_{\max} to 900 nm) were calculated.

We developed a formula for apparent amylose content based on iodine colorimetric analysis. Estimation formula is as follows:

$$\text{AAC} = 73.31 \times A\lambda_{\max} + 0.11 \times \lambda_{\max} - 73.02 \quad (1)$$

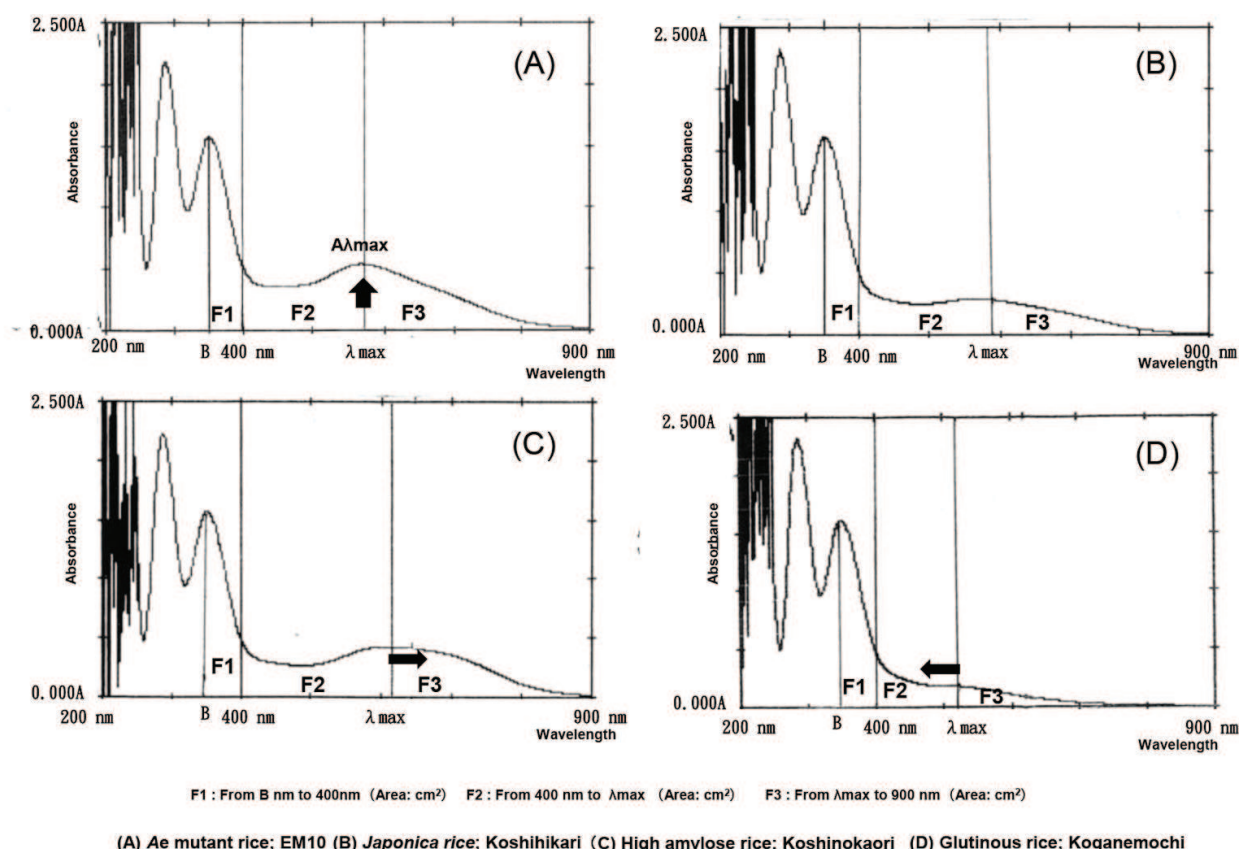


Figure 4. Analysis of iodine absorption curve of various starch samples.

Chain length distribution (CD) was carried out by the method of Hanashiro et al. using HPAEC-PAD of isoamylase-debranched materials of starch:

$$Fb3 = 44.69 \times A \lambda_{\max}^{-0.77} \quad (2)$$

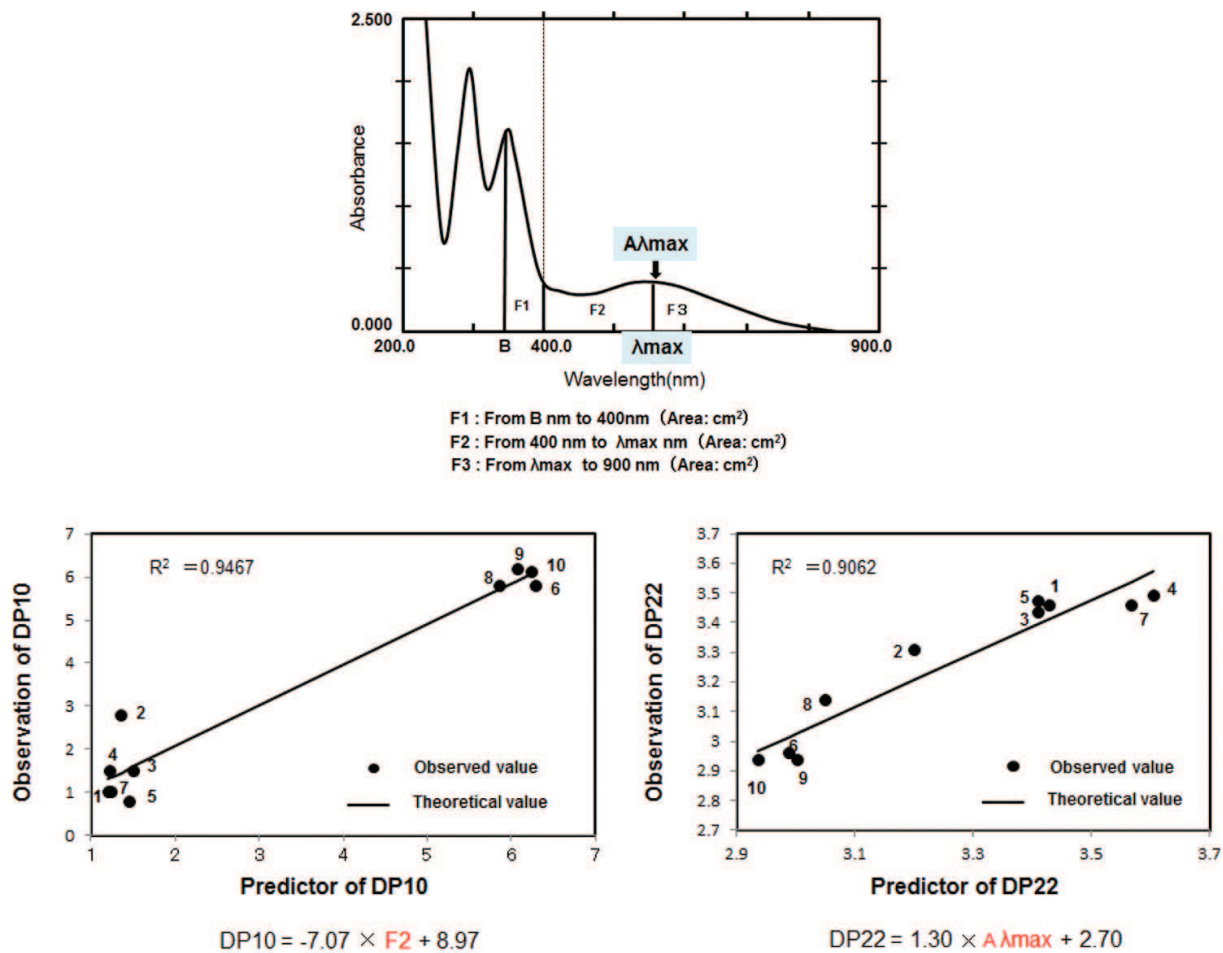
RS in the starch of rice flour was measured according to the AOAC method using a RS assay kit (Megazyme, Wicklow, Ireland) in which each sample (100 mg) was digested by pancreatin and amyloglucosidase at 37°C for 6 h, followed by the measurement of glucose at 510 nm:

$$RS = 21.31 \times A \lambda_{\max}^{-0.030} \times \lambda_{\max} + 12.25 \quad (3)$$

Fraction of DP10 (short chain glucans of amylopectin) and fraction of DP22 (medium chain glucans of amylopectin) were estimated based on F2 area and $A \lambda_{\max}$ based on the iodine colorimetric analyses, respectively, as shown in Figure 5.

4.3. Conclusion

We found that the iodine absorption curve differed between the Indica rice, Japonica rice, Japonica-Indica hybrid rice, *ae* mutant rice cultivars, and glutinous rice cultivars. We propose a novel index, “new λ_{\max} ” based on iodine absorption curve, which shows higher correlation with amylose, resistant starch, or CD of amylopectin than ordinary λ_{\max} .



1, EM10; 2, Hoku243; 3, EM189; 4, EM72; 5, EM129; 6, EM21; 7, EM16; 8, Kinmaze; 9, Koganemochi; 10, Hakuchomochi

Figure 5. Estimation of fraction DP10 and fraction DP22 based on iodine colorimetric analyses.

We developed the novel estimation formulae for AAC, RS contents, amylopectin chain lengths (Fa; DP ≤ 12, Fb3; DP ≤ 37), and fraction of DP10 (short chain glucans of amylopectin) and fraction of DP22 (medium chain glucans of amylopectin) on the basis of the iodine absorption curve. These formulae would lead to an easy and low-cost spectroscopic method for the starch characteristics.

5. Examples of physicochemical measurements of rice palatability

5.1. Comparison of physicochemical properties between Japanese and Chinese rice cultivars

As described in Section 3, in the case of physicochemical evaluation, we can get the common results for the rice samples produced in different countries if we use the same method. As an example, we report the results of physicochemical measurements of rice palatability using rice samples produced in Japan and China.

5.1.1. Introduction

China is the largest rice-producing country, accounting for 32% of the global production from 20% of the global rice-growing area. China produces Indica subspecies mainly in the southern region and Japonica subspecies mainly in the northern region (Heilongjiang, Liaoning), and eastern or southern region (Jilin, Jiangsu, Zhejiang, and Yunnan), whereas the other three countries, India, Indonesia, and Bangladesh, primarily grow Indica rice. In China, consumers are now choosing Japonica rice based on its shape and color as well as its texture and taste. Zhang et al. performed a sensory test of Chinese Japonica rice cultivars [17], in which a Chinese panel mainly determined the overall eating quality based on the stickiness and hardness. In the present section, we conducted physicochemical evaluations of some Chinese and Japanese Japonica rice cultivars using traditional and novel indicators based on the iodine absorption curve and RVA.

5.1.2. Materials and methods

We used high-quality premium Japanese Japonica rice (Koshihikari, Tsuyahime, Yumepirika, Sagabiyori, and Kinumusume) and Chinese Japonica rice cultivars (Kenjing 5, Shendao 529, Jinyuan 45, Changyou 5, Lianjing 7, Longjing 31, Nanjing 9108, Jinongda 878, Shennong 265, Daohuaxiang, and Jinchuan 1) as rice samples.

5.1.2.1. Measurement of the moisture content of rice flour

The moisture content of the milled rice grains was measured using an oven-drying method by drying 2 g flour samples for 1 h at 135°C.

5.1.2.2. Protein content

Nitrogen was determined using a nitrogen analyzer based on the combustion method. The protein content was obtained by multiplying a nitrogen-protein conversion factor of 5.95.

5.1.2.3. Measurement of iodine absorption spectra

The iodine absorption spectrum of milled rice was measured using a Shimadzu UV-1800 spectrophotometer. The apparent amylose content (AAC) of milled rice was estimated using the iodine colorimetric method (as described by Juliano [2]). The iodine absorption spectrum [14] was analyzed from 200 to 900 nm using a square cell of which inner dimension was 1 cm × 1 cm.

5.1.2.4. Measurement of pasting properties of rice flours

The pasting properties of starch rice flours were analyzed using an RVA (model Super 4; Newport Scientific Pty Ltd, Warriewood, Australia). A programmed heating and cooling condition was followed as described by Toyoshima et al. [3]. Novel indices, such as the setback/consistency (SB/Con) and maximum viscosity/minimum viscosity (Max/Fin) ratios, have very strong correlations with the proportion of intermediate and long chains of amylopectin: Fb_{1+2+3} ($DP \geq 13$) [14].

5.1.2.5. Physical properties of boiled rice grains

The boiled rice samples were kept in the vessel at 25°C for 2 h and then subjected to the measurements. The hardness and stickiness of the boiled rice grains were measured using a Tensipresser (My Boy System, Taketomo Electric Co., Tokyo, Japan) using “low compression (25%) and high compression (90%) test” [6]. The average of each parameter was calculated by measuring 20 individual grains. As a staling test of the cooked rice, the cooked samples were stored at 10°C for 16 h and measured again with a Tensipresser according to the previously described method [6].

5.1.2.6. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE)

Proteins were extracted from milled rice flour samples (0.5 g) by shaking with 2 mL of buffer A (50 mM Tris-HCl, pH 6.8, 2% SDS, 5% 2-mercaptoethanol) at 37°C for 30 min and then centrifuged for 5 min at 3000 × g. The supernatant (1 mL) was diluted with an equal volume of sample buffer (0.125 M Tris-HCl, pH 6.8, 10% 2-mercaptoethanol, 4% SDS, 10% sucrose, 0.004% bromophenol blue) and mixed well, followed by heating for 2 min at 100°C. In total 10 µg of extracted protein was charged into each lane. SDS-PAGE was conducted with a 12% polyacrylamide gel according to the modified method described by Laemmli [18]. The values were calculated based on the intensities of various bands on the gel after SDS-PAGE analysis using the ATTO densitograph software library (CS Analyzer ver 3.0).

5.1.3. Results and discussion

5.1.3.1. Main chemical components

Protein is a very important component of milled rice, and it affects the physical properties of cooked rice grains. Higher protein content makes the rice grains harder and less sticky. The protein content of milled Japonica rice is around 6.5%. The protein contents of Chinese rice cultivars (6.8–9.0%; mean = 7.8%) were significantly higher than those of Japanese rice varieties (6.2–6.8%; mean = 6.5%).

AAC has been used as a good parameter for estimating the cooking or eating quality of rice grains, and the iodine colorimetric method for AAC measurement at 620 nm was developed by Juliano [2]. AAC comprises a large amount of amylose and a small amount of SLC in amylopectin. In general, low amylose rice becomes soft and sticky after cooking, whereas high amylose rice becomes hard and separated. The AAC values for Chinese rice cultivars (6.6–17.2%; mean = 14.3%) were higher than those of Japanese rice cultivars (9.7–14.6%; mean = 12.7%). In our previous study [14], we showed that the iodine absorption curve differed among various samples of rice cultivars, and we developed a novel formula for estimating AAC. ($AAC = 73.31 \times A\lambda_{\max} + 0.11 \times \lambda_{\max} - 73.02$). It was shown that a multiple coefficient of determination of 0.996 was obtained when we used this formula to estimate AAC for Chinese rice cultivars.

The molecular structures of many starches, including the molecular sizes of amylose and the amylopectin branch chain lengths, have been reported previously [19–22]. The high molecular weight amyloses tend to have a longer wavelength for λ_{\max} . We found that the glutinous

rice cultivars had very low λ_{\max} values, and Indica rice, Japonica-Indica hybrid rice cultivars, and a high-amylose Japonica rice cultivar had higher λ_{\max} values. The λ_{\max} values of Japonica rice cultivars were intermediate [14].

The “new λ_{\max} ” values are assumed to be related to the SLC content of amylopectin [14]. It was shown that the “new λ_{\max} ” values of the Chinese rice cultivars (0.11–0.27; mean = 0.23) were lower than those of the Japanese rice cultivars (0.23–0.26; mean = 0.25).

The starches in the rice cultivars grown under low temperatures have a significantly higher amylose contents than those of the rice cultivars grown under high temperature, whereas the SLC contents of the amylopectin were lower [23–27]. Thus, we consider that the starch properties of Japanese rice cultivars were influenced by the ambient temperatures during the development of the grain, which yielded high “new λ_{\max} ” values.

5.1.3.2. Physical properties of cooked rice grains

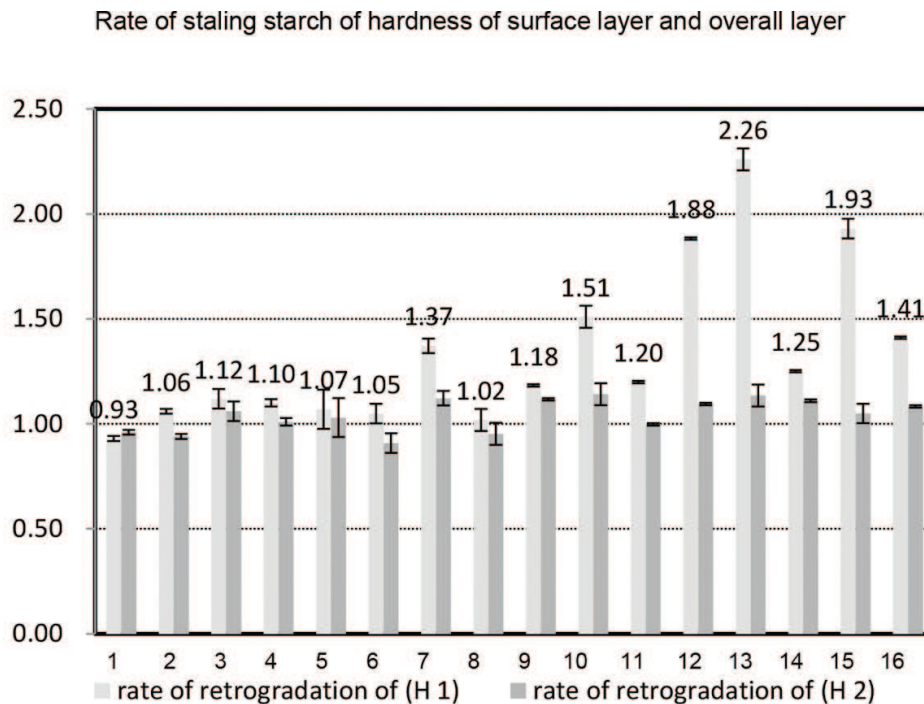
There were differences in the values of physical properties of the cooked rice grains. The balance of -H1/H1, -H2/H2, A3/A1, and A6/A4 are important indices when evaluating the palatability of rice [16].

The hardness of the surface layer (H1) was higher in the Chinese rice cultivars than the Japanese rice varieties, and the hardness of the overall layer (H2) of Chinese rice cultivars was higher than that of the Japanese rice varieties. The stickiness of the surface layer (-H1) was significantly lower in the Chinese rice cultivars than the Japanese rice cultivars, whereas the stickiness of overall layer (-H2) was higher in the Chinese rice varieties than the Japanese rice cultivars. The balance degree of the surface layer (-H1/H1) was significantly lower in the Chinese rice varieties than the Japanese rice varieties, and that of the surface layer (A3/A1) was significantly lower in the Chinese rice varieties than the Japanese rice varieties.

Low amylose rice cultivars are stale-resistant according to Takami et al., who previously reported the staling characteristics of cooked low amylose rice [28]. In the staling test, we stored the cooked rice at 10°C for 16 h (**Figure 6**). The staling rate for starch based on the surface layer hardness (H1) was significantly higher in the Chinese rice cultivars than the Japanese rice cultivars. In particular, Jinongda 878 (2.3 times), Daohuaxiang (1.9 times), and Nanjing 9108 (1.9 times) had very high values. The staling rates for starch based on the hardness of the overall layer (H2) were almost the same in the Chinese and Japanese rice cultivars. The staling rate for starch based on the hardness of the surface layer (H1) in Chinese rice varieties had a positive correlation with the intensities of the 13 kDa prolamin spots and the protein content at $p < 0.01$.

5.1.3.3. SDS-PAGE

The intensities of the bands of 13 kDa prolamin were correlated positively with $\lambda_{\max}/A\lambda_{\max}$ ($r = 0.66$) and “new λ_{\max} ” ($r = 0.65$) in Chinese rice varieties, and with the glutamic acid ($r = 0.85$), whereas with λ_{\max} ($r = -0.65$) had negative correlation.



1, Koshihikari; 2, Tsuyahime; 3, Yumepirika; 4, Sagabiyori; 5, Kinumusume;
 6, Kenjing 5; 7, Shendao 529; 8, Jinyuan 45; 9, Changyou 5; 10, Lianjing 7; 11, Longjing 31;
 12, Nanjing 9108; 13, Jinongda 878; 14, Shennong 265; 15, Daohuaxiang; 16, Jinchuan 1

Figure 6. Results of the staling starch test of the physical properties of cooked rice grains.

The rice seed storage proteins mainly comprise glutelins and prolamins. PB-I is highly enriched with prolamins and it constitutes approximately 20% of the milled rice protein contents. PB-II mainly contains glutelins and it constitutes 60–65% of the milled rice protein [29]. The protein content of rice grains is influenced by the weather conditions, as it is increased by high air temperature or high water temperature, but decreased by low water temperature or sun shading during the ripening stage [30]. Matsui et al. [31] showed that the Final vis. and Cons values of near-isogenic line pairs for the low glutelin gene (*Lgc1*) locus were significantly higher in low glutelin lines, and the surface stickiness was also significantly lower in the low glutelin lines. Protein production also tended to increase with higher levels of nitrogenous fertilizer at any planting density [32].

5.1.4. Conclusion

In this study, we evaluated 16 Japanese and Chinese rice cultivars in terms of their main chemical components, iodine absorption curve, apparent amylose content (AAC), pasting property, resistant starch content, physical properties, and SDS-PAGE.

Based on these quality evaluations, we can conclude that Chinese rice cultivars are characterized by their high protein content. The hardness of the surface layer (H1) and overall layer

(H2) were higher in the Chinese rice cultivars than the Japanese rice cultivars, whereas the stickiness of the surface layer, and the balance degree of the surface layer were lower in the Chinese rice cultivars than the Japanese rice cultivars, although the stickiness of the overall layer (-H2) was higher in the Chinese rice cultivars than the Japanese rice cultivars. In addition, the texture of cooked rice was strongly correlated with the iodine absorption factors.

In a previous study, we developed a novel formula for estimating AAC based on the iodine absorption curve. The validation test showed a determination coefficient of 0.996 for estimating AAC of Chinese rice cultivars as unknown samples.

5.2. Palatability evaluation of the Japanese premium rice “Koshihikari” in Sado Island

As described in Section 3, in the case of physicochemical evaluation, we can get the common results for the rice samples produced in the different regions if we use the same method. As an example, we report the results of physicochemical measurements of rice palatability using rice samples produced by the different cultivation conditions, and rice samples grown in the mountainous region and the field region in Sado Island, Japan.

5.2.1. Introduction

Rice is one of the most important staple foods in the world. “Koshihikari” is the most famous premium rice cultivar, and it shares about 37% of all rice production in Japan. “Koshihikari” is cultivated all over Japan, but that grown in Niigata Prefecture is considered the best “Koshihikari” in Japan with regards to its quality and quantity. Sado Island is part of the Niigata Prefecture and the “Koshihikari” cultivated in Sado, Iwafune, and Uonuma is evaluated as the highest quality rice.

Sado Island is located off the Niigata City seashore and it is the second largest island in Japan after Okinawa Island. Sado Island is famous for its Toki (crested ibis, *Nipponia nippon*), which is an endangered species in Japan. The inhabitants of Sado city and its farmers are trying to make an ideal habitat for Toki. The feed for Toki are small fish and insects, such as the loach, grasshoppers, and worms as well as small river crabs, and frogs. The farmers are making an effort to keep the environment agriculturally sound to protect the ibis from extinction.

Sado city awards the farmers a harmonizing environment certificate known as the “homeland to live with crested ibis” if the farmers adopt an ibis-friendly agricultural method. Farmers create a narrow pond, preserve bio-diversity with winter-flooding, and reduce the use of chemical fertilizers and agricultural chemicals by over 50% compared with conventional cultivation.

However, the effects of this ibis-friendly agricultural method, which also include abolishing drying paddy field after transplanting, does not equate to palatability of the rice grains. Therefore, the relationship between the palatability of rice and agronomical condition to preserve the bio-diversity for ibis was investigated. Furthermore, the quality of rice grown in Sado Island was compared with that of rice grown in mountainous areas and in the field.

5.2.2. Materials and methods

5.2.2.1. Comparison of Sado Koshihikari and the other premium rice in Japan

Ten premium rice cultivars, including “Koshihikari” from Sado Island, “Sagabiyori,” “Yumepirika,” “Akitakomachi,” “Tsuyahime,” “Hitomebore,” and “Koshihikari from Sado” were subjected to physicochemical measurements and sensory test.

5.2.2.2. Comparison of mountainous and field regions

Rice samples grown in eight regions, including the mountainous and field regions, were subjected to the physicochemical measurements to evaluate rice quality.

5.2.2.3. Effects of the ibis-friendly cultivations on the palatability of the rice grains

Rice grains were harvested after an ordinary or ibis-friendly cultivation and were subjected to quality evaluations. Ibis-friendly cultivation meant that farmers adopted winter-flooding (keeping water even during the winter season to save the habitat for Toki in winter) or deletion of “Nakaboshi” (drainage of paddy field for approximately a week after transplanting to activate the roots of rice plant).

5.2.2.4. Preparation of polished rice samples

After de-husking, brown rice was polished to a milling yield of 90–91%, using an experimental TM05 rice milling machine (Satake, Co. Ltd. Higashihiroshima, Japan). Rice flours were prepared by a cyclone mill (SFC-S1, Udy, Fort Collins, CO, USA).

5.2.2.5. Amylose content

Amylose content was measured by the iodine colorimetric method. Calibration samples were prepared by mixing the standard potato amylose (Type III, Sigma Chemical Co., St. Louis, MO, USA) and standard amylopectin (waxy rice removed from fat and proteins).

5.2.2.6. Measurements of protein content, Mido, and quality score

Protein contents and quality scores were measured with a near-infrared spectrometer (AN820, Kett Electric Laboratory Co. Ltd., Tokyo, Japan) (Near Infrared Spectrometer, Foss Japan Co. Ltd, Tokyo, Japan). Mido was measured using a Midometer (Toyorice, Wakayama, Japan).

5.2.2.7. Measurement of the physical properties of the boiled rice grains

Polished rice grains (10 g) were added with 16 mL of distilled water in an aluminum cup. The rice was in the water for 1 h, cooked for 25 min in the automatic electric rice cooker (SR-SW182, Panasonic Co. Ltd., Kadoma, Japan) and kept warm for 10 min in it. After the rice was kept warm, the boiled rice grains were moved into a plastic bag and kept in the bag for 2 h at 25°C. Thereafter, the physical property (hardness and stickiness) of each boiled rice

grain (20 samples) was measured by a Tensipresser (My Boy System, Taketomodeni Co. Ltd., Tokyo, Japan), as reported by Okadome et al. (single grain low-compression high-compression test).

5.3. Results and discussion

5.3.1. Comparison of palatability of premium rice cultivars in Japan

“Koshihikari” from the Sado Island received extremely high value for the quality value, Mido value, and low value for protein. “Koshihikari” from Sado Island had an extremely low hardness in surface layer of boiled grains, whereas extremely low amylose rice such as “Yumepirika” had the lowest hardness in surface layer of boiled rice gains. The ratio of stickiness to hardness of surface layer of boiled grains was the highest for “Yumepirika” followed by “Koshihikari” from Sado Island. Palatability of the “Koshihikari” from Sado Island seems to be one of the best premium rice cultivars in Japan due to its low protein content.

5.3.2. Comparison of mountainous and field regions

As a result of measurement of physical properties, five rice samples from mountainous regions showed a lower pasting temperature and a higher ratio of adhesiveness to hardness (A6/A4, overall). It was reported that the ratio of adhesiveness to hardness is correlated with palatability of boiled rice grains. Rice samples grown in the mountainous region seems to be more palatable than those in the field region because the former rice is more adhesive.

5.3.3. Effect of winter-flooding and Nakaboshi on palatability of rice

Rice samples grown using winter-flooding (without “Nakaboshi”) showed higher amylose contents, than those grown with winter-flooding and “Nakaboshi.” Rice grains grown using winter-flooding and Nakaboshi had lower amylose contents implying that the boiled rice grains of this group were softer and stickier than the rice grains subjected to winter-flooding alone. In case of cultivation using winter-flooding, the rice grains grown using “Nakaboshi” became stickier after boiling compared with those cultivated without “Nakaboshi.” In case of cultivation without Nakaboshi, rice samples grown using winter-flooding became less adhesive after boiling compared with those grown without winter-flooding. These results are shown in **Figure 7**.

To summarize, farmers should adopt Nakaboshi in case of winter-flooding, and avoid winter-flooding in case of not performing Nakaboshi. Although adoption of winter-flooding and not performing Nakaboshi are recommended to maintain biodiversity, simultaneously performing of both of these measures negatively affects the palatability of the boiled rice grains.

5.4. Conclusions

Farmers in Sado city make an effort to harmonize the environment with sound agriculture to protect the ibis from extinction. The palatability of “Koshhikari” from Sado Island is among

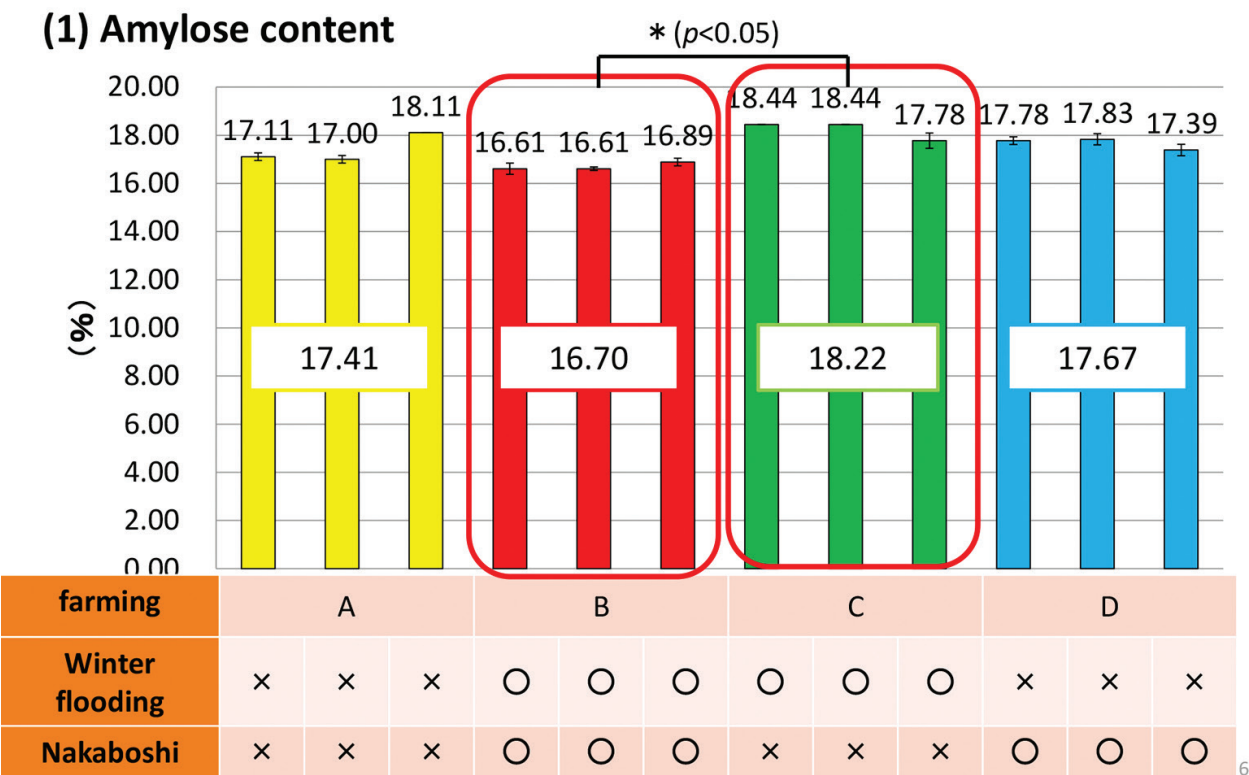


Figure 7. The effect of winter-flooding and Nakaboshi on amylose contents of rice grains.

the premium rice cultivars in Japan. The rice quality from Sado Island grown in mountainous areas and those in field regions were examined along with the palatability of rice and the agro-nomical conditions to preserve the bio-diversity for the ibis.

The results show that the palatability of “Koshihikari” from Sado Island seems to be one of the best among the premium rice cultivars in Japan because of its low protein contents. Five rice samples from mountainous regions showed better physical properties compared with three rice samples grown in the fields. Adoption of both winter-flooding and not performing Nakaboshi is recommended to maintain biodiversity; however, simultaneously performing both of these measures negatively affects the palatability of the boiled rice grains.

6. Summary

There are various kinds of rice cultivars of which qualities are diversified, such as hard Indica rice and soft Japonica rice in the world. Consumers in southern Asia prefer hard rice grains and people in North-eastern Asia like soft and sticky rice grains. Novel method to evaluate the quality of the cooked rice is necessary to breed high-quality rice cultivars and to select the suitable rice for each consumer and for each purpose. We try to develop the novel method to evaluate the rice quality using various kinds of apparatus, such as Tensipresser, RVA, NIR,

and spectrophotometer. Simple, rapid, and accurate method to evaluate the quality of rice grains is very valuable.

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